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The analysis of wind data and wind energy potential in Kutahya, Turkey

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Abstract

The wind energy is one of the most significant and rapidly developing renewable energy sources in the world and it provides a clean energy resource, which is a promising alternative in the short term in Turkey. The wind energy potential in various parts of Turkey is becoming economical due to reductions in the wind turbine costs, and in fossil fuel atmospheric pollution. Because of this, it is necessary to make use of this resource immediately and start conducting the required technical and economical feasibility research. The main purpose of this paper is to present, in brief, wind potential in Turkey and to perform an investigation on the wind energy potential of Kutahya. Therefore, in this study, a wind observation station was established at Dumlupinar University Main Campus in order to figure out the wind energy potential in the province. Topographical and wind speed measurement data have been collected as a first step. The wind speed has been measured at the 10th and 30th meters of the measurement mast for 20 months. The data collected in this observation station between July 2001 and February 2003 have been evaluated via CALLaLOG 98 and ALWIN software programs. The wind energy potential of the location has been studied based on the Weibull and the Rayleigh models. Weibull approximation was found to be better than that of Rayleigh model.

Keywords: Turkey; Wind energy; Wind data; Wind measurement mast; Weibull distribution

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1. Introduction

Limited reserves of fossil fuels and their negative impacts on the environment lead institutions, organizations and governments to find out more efficient technologies and new and renewable energy resources to produce energy in the natural environment. Recently, wind energy is the growing energy source in the world and wind power is one of the most widely used alternative sources of energy [1]. The wind energy has been used for centuries for navigation and agriculture. Today, the use and the technology of the wind energy have been developing very fast. As of the end of 2002, total global wind generating capacity exceeds 31,000 MW, and provides about 65 billion kW h of electricity annually [2]. Approximately, 6800 MW of new capacity were installed worldwide in 2002. Generating capacity is mainly concentrated in just five countries: Germany (38.5%), Spain (15.5%), the US (15%), Denmark (9.3%) and India (5.5%) together account for 83.8% of the total [3].

The effective utilization of the wind energy entails having a detailed knowledge of the wind characteristics at the particular location. The distribution of wind speeds is important for the design of wind farms, power generators and agricultural applications such as the irrigation. It is not an easy task to choose a site for a wind turbine because many factors have to be taken into account [1].

In this study, the wind energy potential in Kutahya is investigated in 20 month measured wind speed data. Firstly, a wind observation station was established inside the Dumlupinar University Main Campus, which is located at windward and high altitudes of Kutahya. Secondly, the data collected in this observation station between on July 1, 2001 and February 28, 2003 and finally, the data have been evaluated via CALLaLOG 98 and ALWIN software programs. The wind energy potential of the region has been studied based on the Weibull and the Rayleigh models.

2. The wind energy potential in Turkey

More than half of the energy requirement of Turkey is being imported, and the air pollution is becoming a great environmental concern in the country [4].

Environmental pollution caused mainly by use of fossil fuels in order to meet increasing demand for energy have become an important matter in Turkey's agenda during the last decades. It has been observed that there has been a tendency towards the clean and renewable energy sources in Turkey, as in the whole world. The geographical location of Turkey has several advantages for extensive use of the most of the renewable resources. In this regard, Turkey has to make use of its renewable resources, such as wind, solar and geothermal, not only to meet the increasing energy demand, but also for environmental reasons [5,6].

Before making plans or programs related to the use of the wind energy, it is necessary to discover the potential of this resource. Therefore, public institutions and universities have been striving to measure the wind potential and to conduct certain research projects about this resource [7–15]. However, further studies on the assessment of wind energy in Turkey are necessary. The Electrical Power Resources Survey and Development Administration (EIE) have started to compile a Wind Energy Atlas in conjunction with the Turkish State Meteorological Service (DMI) [16,17]. This book provides maps of estimated wind energy classes for each region, as well as information about climate, topography and wind resource measurement. The wind data used in these calculations have been measured hourly and collected from 45 stations measuring the wind speed, spread all over the country. The recently published the Turkish Wind Atlas has reaffirmed the great potential that is yet to be exploited in the country [18]. The Atlas was prepared by using WA^{S}P (Wind Atlas Analysis and Application Program) model used for European Wind Atlas. According to wind atlas, the country can be divided into four main windy regions as shown in Fig. 1. In region 1, the wind speed is in the range of

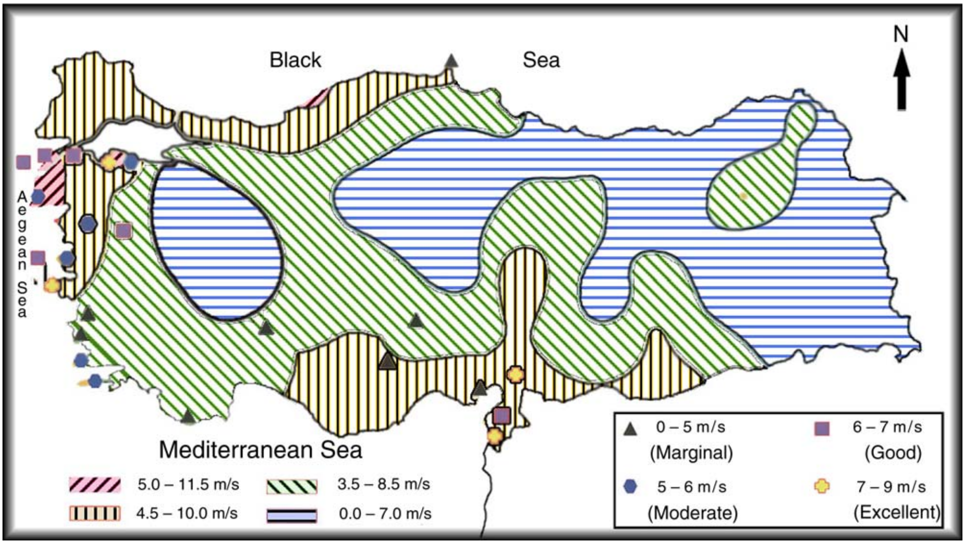

Fig. 1. Scattering of wind velocity and wind observation station in 10 m high [18].

5–11.5 m/s. In region 2, the wind speed is in the range of 4.5–10 m/s, while in regions 3 and 4 the wind speed is in the range of 3.5–8.5 m/s, 0–7 m/s, respectively. With an annual average wind speed and power density of about 2.5 m/s and 25.8 W/m^2, respectively, the western, northern and southeastern coasts of Anatolia have been identified as very favorable locations for wind power generation according to the existing official data [18]. The central Anatolia region does not provide potential wind energy locations. Especially, many islands in the Aegean Sea such as Bozcaada in the northern Aegean region have high wind power generation possibilities in addition to some suitable locations along the coastal line especially in Cesme on the Anatolian main land. These regions are highly suitable for the wind energy generation, since the wind speeds exceed 3 m/s in most of these areas.

In Turkey, the wind energy utilization is generally critical in transitional seasons where the annual maximum and minimum values occur. However, some stations have different characteristics from each other because of topographical and local climatological conditions. Wind speed measurement stations for some selected cities in Turkey are given in Table 1, and the same table shows the geographical locations, altitudes and the average wind speeds as raw data [16]. Accordingly, the most attractive cities for wind energy applications are Kocadag, Bandırma, Gelibolu, Gokceada, Akhisar and Bodrum. These regions are highly suitable for wind power generation, since the wind speed exceeds 5 m/s in these areas. Using the annually averaged wind speed data of the last five years (1998–2002), the maximum value (8.2 m/s) is in the Kocadag station and the minimum (4.1 m/s) is in the Didim station.

Although Turkey has a favorable wind resource, the use of wind energy in Turkey is too limited. The total installed capacity has reached 19.1 MWe in three wind power stations in 2002. The first wind power facility commissioned in

Table 1
Annual wind speeds from wind data acquisition station of EIE [16]

Station	Latitude (N)	Longitude (E)	Altitude (m)	Average wind speed at 10 m (m/s)					
				1998	1999	2000	2001	2002	Mean
Akhisar (Manisa)	38° 55′	27° 51′	93	6.3	6.1	6.0	5.9	5.4	5.9
Bandırma	40° 21′	27° 58′	58	N/A	N/A	N/A	8.0	6.4	7.2
Didim (Aydın)	39° 03′	26° 52′	3	N/A	N/A	N/A	4.2	3.9	4.1
Gelendost (Isparta)	37° 46′	30° 33′	1004	4.7	5.0	4.8	5.0	4.4	4.8
Gelibolu	40° 40′	26° 62′	27	8.6	6.4	6.4	6.8	5.8	6.8
Gokceada	40° 11′	25° 54′	72	6.9	6.4	6.1	7.2	6.3	6.6
Kocadag (Cesme)	38° 61′	26° 51′	1218	8.4	8.2	8.2	8.8	7.4	8.2
Sinop	42° 02′	35° 10′	32	4.7	4.2	4.4	4.6	3.8	4.3
Yalıkavak (Bodrum)	37° 09′	27° 31′	545	6.2	6.3	6.2	5.1	5.2	5.8

February 1998 is located near the city of Izmir in western Turkey, and has a capacity of 1.7 MWe. The second wind power facility started to operate in November 1998, which incorporates 12 wind turbines of a total capacity of 7.2 MWe in Alacatı, Izmir. The third wind power generation utility, in operation since June 2000, has a total installed capacity of 10.2 MWe (17 wind turbines) and is located in Bozcaada, Canakkale. Indeed, the wind energy potential is high in Turkey though commercial wind energy is new. The Ministry of Energy and Natural Resources (MENR) is preparing draft legislation which would allow certain renewable energy projects (mainly geothermal, wind, and solar) to be built and operated by the private sector, and provide incentives for such systems. In this result, the estimated wind energy capacities are 2100 MWe in 2010. According to this target, by the year 2010 the share of electrical energy from wind energy should increase to 2% of the total amount of electrical energy used in Turkey [19].

3. Materials and methods

The city of Kutahya, (39° $42'$ N, 29° $93'$ E, 170,000 inhabitants), is located at the central western part of Turkey. It is situated on a plateau surrounded by mountains to the east, and south. The height of the plain on which the city is located is 969 m above the sea level. The region has a typical terrestrial climate (cold and wet in winter, but hot and arid or semiarid in summer).

In general, Kutahya has low wind speeds and therefore, limited wind energy potential. However, there may be specific sites and applications where wind is a cost-effective option. The wind speed, which varies proportional to the altitude, is among the main factors that determine the wind energy potential. A site's average wind speed is very important because a small difference in wind speed has a major effect on the amount of wind power available. Therefore, the position of the wind observation station should be chosen correctly, the appropriate wind measurement equipment should be used and then, the recorded data should be evaluated [1]. While determining the position of the wind observation station established in the Dumlupinar University Main Campus, the buildings and the other factors have been taken into account and ensured that there were not any obstacles at the windward side of the station.

The wind observation station, which is situated at 1100 m high above the sea level and at the co-ordinates of 29° $80'$ longitude and 39° $52'$ latitude stand a mast, on which is fixed equipment erected to measure the wind speed and wind direction at the height of 30 m. And also a solarcell (12 V/5 W) for the energy requirement, a data logger (Wicom-El/Wind computer data logger) for storing the wind speed and the information about directions, thermometer, barometer, hygrometer, and cables and terminals to provide the connection. Furthermore, a computer was used to transfer the data to be evaluated from data logger [14]. The mast has a lightning conductor to avoid the danger of lightning and fixed to the ground with guy. The mast is shown in Fig. 2. The "Ammonit" anemometer, which has been selected due to its simple design and easy use and its technical features are given in Table 2, and

Fig. 2. Mast erected on the main campus.

the calibration of the direction control equipment have been provided by DEWI Institute [20,21].

4. The data and its evaluation

The requirement for the data collected from an observation station to determine the wind energy potential is that the data have to be measured for a period of at least 1-year, but 2 or more years will produce more reliable results. Of course, it is preferable to have the wind speed data for 5 years, if the case is applicable. During the current investigation, the information for the speed and the direction of the wind has been collected for 20 months, making use of anemometers placed at 10th and 30th meters of the measurement mast. The data logger recorded the parameters measured at the observation station for the each second, and the average, minimum, and maximum values and their standard deviations have been measured at 10-min intervals. The field data have been transferred to a laptop computer for analysis. The data have been recorded continuously since the measurement system became operational in July 2001. The recorded wind speed and direction data have been archived in the CALLaLOG 98 software as daily files and monthly folders,

Table 2
Nominal Specifications of the Equipments

Specification	Anemometer	Wind vane	Thermometer	Hygrometer	Barometer
Measurement range	0.3–50 m/s	0°–360° ($\leq 8^\circ$ deadband)	−35 to 80 °C	0–100% RH	800–1600 h Pa
Accuracy	±2%	±2%	±1 °C	±1 RH	–
Starting threshold	$\leq$1.0 m/s	$\leq$1.0 m/s	N/A	N/A	N/A
Resolution	$\leq$0.05 m/s	1°	0.1 °C	1%	1 h Pa

and to evaluate the wind data the ALWIN software has been used. This software allows us to measure the wind energy, and the code takes into account the data recorded and the topographical characteristics of the region. Moreover, this software is capable of determining the location of turbines, the average wind speed potential, the average dominant and strong wind directions and the amount of energy, which can be produced for the current data. The missing data should not exceed 10% according to the standards [22]. Among all the data collected during this research, the amount of lost data is not over 2%.

5. Results and discussion

Approximately, for a period of 2 years (2001–2003) of the wind speed, direction, air temperature, relative humidity and barometric pressure, the data collected for an interval of 10 min at the measurement mast of 30 m height have been used to analyze the wind energy potential of Kutahya. The maximum and minimum monthly average temperatures have been 21.5 °C in July 2002 and 0.2 °C in January 2002. The maximum atmospheric pressure value of 894 h Pa and minimum average value of 886 h Pa has been observed, in December 2002 and in April 2002, respectively. The average temperature, relative humidity, and barometric pressure are 10.4 °C, 67%, and 890 h Pa, respectively.

Determining the wind speed according to wind direction is important to conduct the wind energy researches and also displays the impact of geographical features on the wind. The reference point of the direction control equipment, where the temperature is 0 °C, is northeast. According to Fig. 3, the most windward directions are southeast and northwest, and the directions where the wind is strongest are northwestern and southeastern regions.

It is important for the wind industry to be able to describe the variation of the wind speeds. The wind speed has been measured by two anemometers located at 10

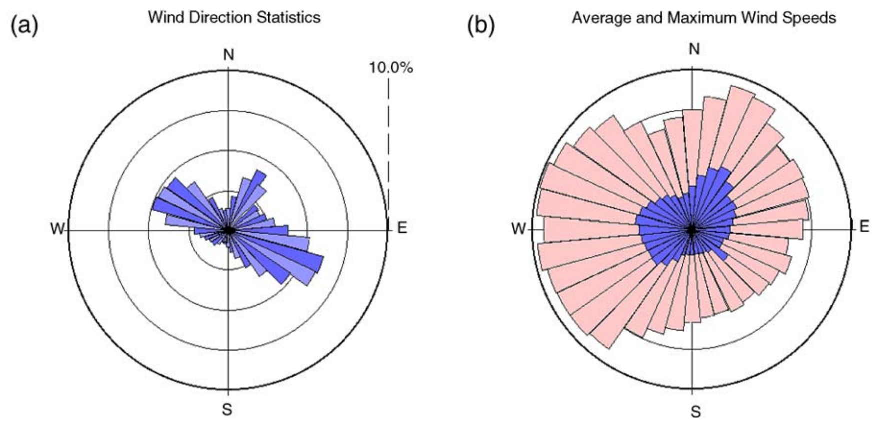

Fig. 3. A wind rose from the Kutahya site: (a) the main wind directions; (b) the mean wind speeds.

and 30 m height on the measurement mast for 20 months. The reason for measuring wind speeds at two different heights was to calculate wind shear value. The monthly distribution of the wind speed measured between July 1, 2001 and February 28, 2003 is plotted in Fig. 4. It can be seen from this figure that the wind speeds vary between 3.4 and 6.1 m/s. According to these results, the average speed for 10 m is 4.46 m/s and it is 4.62 m/s for 30 m. This is below the minimum speed, 5.0 m/s, required for effective wind turbines, but it is enough for water pumping applications. The best way to evaluate the wind resource available at a potential site is by calculating the wind power density. It indicates how much energy is available at the site for conversion to electricity by a wind turbine. The mean value of wind power density has been calculated as 36.62 W/m^2. If the variation of the wind speed measured for 20 months between July 2001 and February 2003 is examined according to the seasons, it is found out that the wind speed is maximum in winter months, it reduces in autumn and reaches its minimum level (3.58 m/s) in October 2002 (at 30 m). The wind speeds starts rising again after this month and reaches the maximum value of 6.1 m/s in February 2003. The wind power density is 79.1 W/m^2 in February 2003 and its minimum level (15.99 W/m^2) is in October 2002. This is due to the fact that this station has a typical terrestrial climate, which is cold and wet in winter with a large variation in ambient temperature.

Fig. 5 shows the daily variation of the hourly average wind speed for January, April, July and October, which are representative of all four seasons, in the station here considered. The hourly average wind speed during the day shows a typical behavior in all four seasons: the magnitude of wind speed is near constant during the night until about eight and nine in the morning, then increases strongly reaching a maximum about at 4.00 p.m. This figure also indicates that the wind speeds decrease slightly in the early morning and evening hours. Daily wind intensity var-

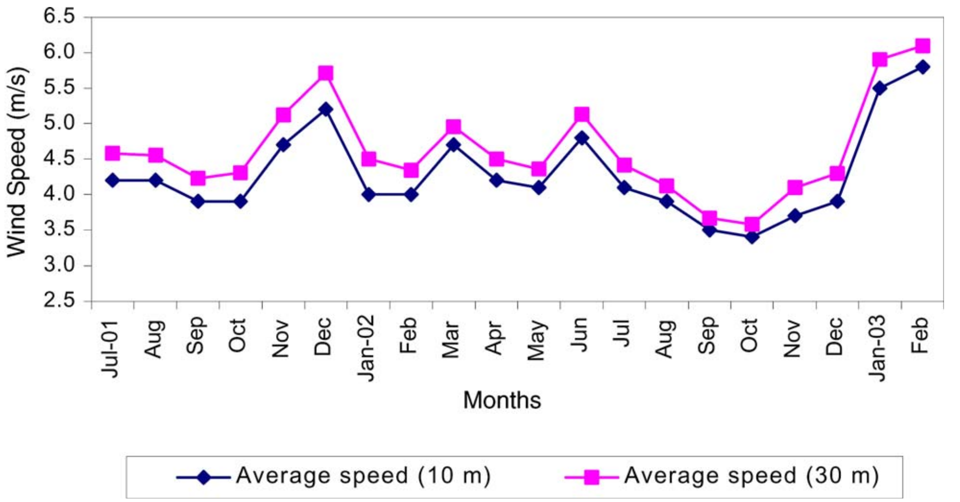

Fig. 4. Distribution of long term monthly average wind speeds at 10 and 30 m height.

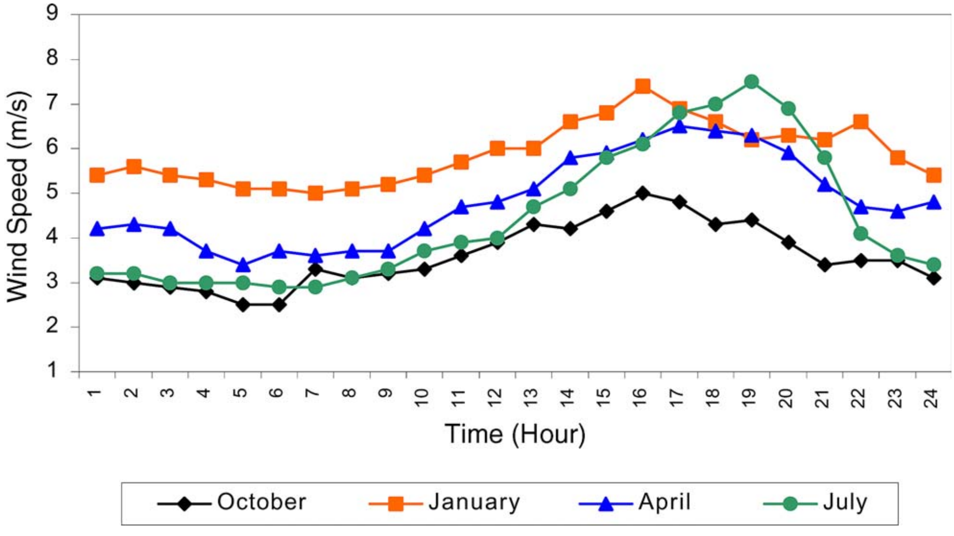

Fig. 5. Diurnal wind speed variations at 30 m height.

iations, which are directly related to daily temperature variations, are low in the mornings, reach a maximum value in the afternoons and start decreasing in the evenings. It is seen from Fig. 5 that hourly wind speeds vary between 4.8 and 7.2 m/s with maxim occurrence in the afternoon.

The numerous studies for different locations of the world have shown that the Weibull two-parameter distributions give an excellent fit to the wind speed distribution. For this reason, the Weibull distribution and its special case, the Rayleigh distribution, have been used to study the wind data. The corresponding average wind speeds and best fits to a two-parameter Weibull distribution are shown in Fig. 6. Weibull-a is the wind speed-normalizing factor, and c is the shape factor in the Weibull wind speed distribution. Fig. 6, plotted by using the data in Table 3, shows the areas where the wind speed values are observed more frequently, and the frequency histogram has been used for the selection of the wind turbines. The variable least squares method has been applied to the observed frequency distribution, and the Weibull-a parameter has been measured as 5.48 m/s, Weibull-c as 1.67 m/s and Rayleigh parameter as 4.89 m/s. Rayleigh and Weibull distributions signify the wind regime in the region and are the most appropriate parameters to the measured frequency distribution. Fig. 6 which illustrates the blowing percentage corresponding to wind density. In this study, Weibull approximation was found to be better than that of Rayleigh model. When Fig. 6 is examined, it can be seen that the wind speed measured in the observation station at the Dumlupinar University Main Campus for 20 months varies from 3 to 5 m/s. Weibull approximation was found to be better than that of Rayleigh model.

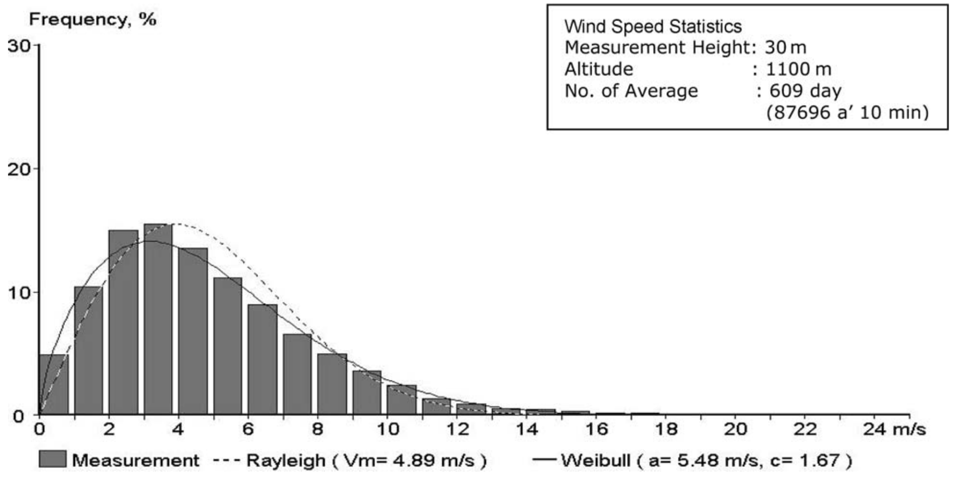

Fig. 6. Frequency Histogram and Rayleigh, Weibull Distribution.

Table 3
Wind speed statistics at 30 m

V, m/s	F(Measurement), %	F(Rayleigh), %	F(Weibull), %
0–1	4.47	3.34	5.35
1–2	10.94	9.36	11.22
2–3	15.08	13.63	13.93
3–4	15.60	15.58	14.44
4–5	13.68	15.29	13.41
5–6	11.19	13.34	11.48
6–7	8.76	10.51	9.20
7–8	6.42	7.56	6.96
8–9	4.86	4.99	5.00
9–10	3.47	3.04	3.42
10–11	2.35	1.71	2.24
11–12	1.18	0.89	1.41
12–13	0.75	0.43	0.85
13–14	0.43	0.19	0.49
14–15	0.29	0.07	0.28
15–16	0.21	0.04	0.16
16–17	0.11	0.02	0.08
17–18	0.08	0.01	0.05
18–19	0.05	0.00	0.02
19–20	0.03	0.00	0.01
20–21	0.02	0.00	0.00
21–22	0.02	0.00	0.00
22–23	0.01	0.00	0.00

6. Conclusion

Since the geography of Turkey provides appropriate meteorological conditions for the wind energy generation, it is inevitable to support the wind energy initiatives. In general, potential wind energy areas in Turkey lie in the northwestern and northern parts and at locations along the Aegean Sea coast. These regions are highly suitable for the wind energy generation, since the wind speeds exceed 3 m/s in most of these areas. However, the whole area of the country should be examined to detect the fields proper for the establishment of the wind turbine farms and public initiatives should start establishing the wind energy farms for the chosen areas.

In this study, the mean wind speed and energy density measured at Kutahya for 20 months reveals that the current technology does not provide the economical electricity production from the wind energy and that measurements should be evaluated in the long term in accordance with technological developments and reduction in the cost of turbines.

Acknowledgements

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